LNAPL Evaluation Approaches

Overview and Recommendations

Presented by Regulatory Agencies

February 2019

Red Hill AOC SOW Contaminant Fate and Transport Priorities

- Protect drinking water receptors and resource
- Protect groundwater resource
- Inform future actions regarding:
  - Release response
  - Sentinel well network placement
  - Infrastructure improvements
- How can the LNAPL vadose zone evaluation support our priorities under the current schedule? F&T Report due April 2020

Navy's Current Approach- LNAPL Holding Model

- Navy's existing LNAPL holding model can not address many of our key concerns related to transport and is generally non conservative
- Current Navy approach does not reasonably bound the uncertainty related to risk to receptors
- May overestimate the time available for potential release response
- Navy's existing LNAPL holding model does not realistically estimate holding capacity

Approach to Address Red Hill's Challenges

- Navy should pursue 2D modeling at this time. Under the current schedule, Navy should be able to:
  - Bound uncertainty in transport distances
  - Inform decision-making for our critical concerns
- 2D modeling can reasonably bound 'worst case' scenarios
- 2D modeling in the vadose zone can be used to provide inputs into the groundwater flow model
- This will require some additional work, but no large data collection effort is foreseen at this time

Technical Rationale and Approaches

Overview and Recommendations

Presented by Matthew Tonkin, SSP&A

February, 2019

"The relative importance of individual flow or transport directions to the investigated problem allows the model user to simplify by reducing the model dimensions"

- 3D models closely approximate natural conditions, but modeling efforts may be extensive. The limiting factor is often the availability of detailed site-specific data. Multi-layer models represent stratified aquifers using 2D layers linked by leakage.
- 2D models neglect flow and transport components in either the horizontal or vertical direction. Thus they yield predictions in two dimensions, averaged in the third dimension.
- 1D models simplify further, often permitting analytical solution to the problem under investigation.
- Zero-dimensional (black box or compartmental) models focus solely on balancing inputs and outputs.

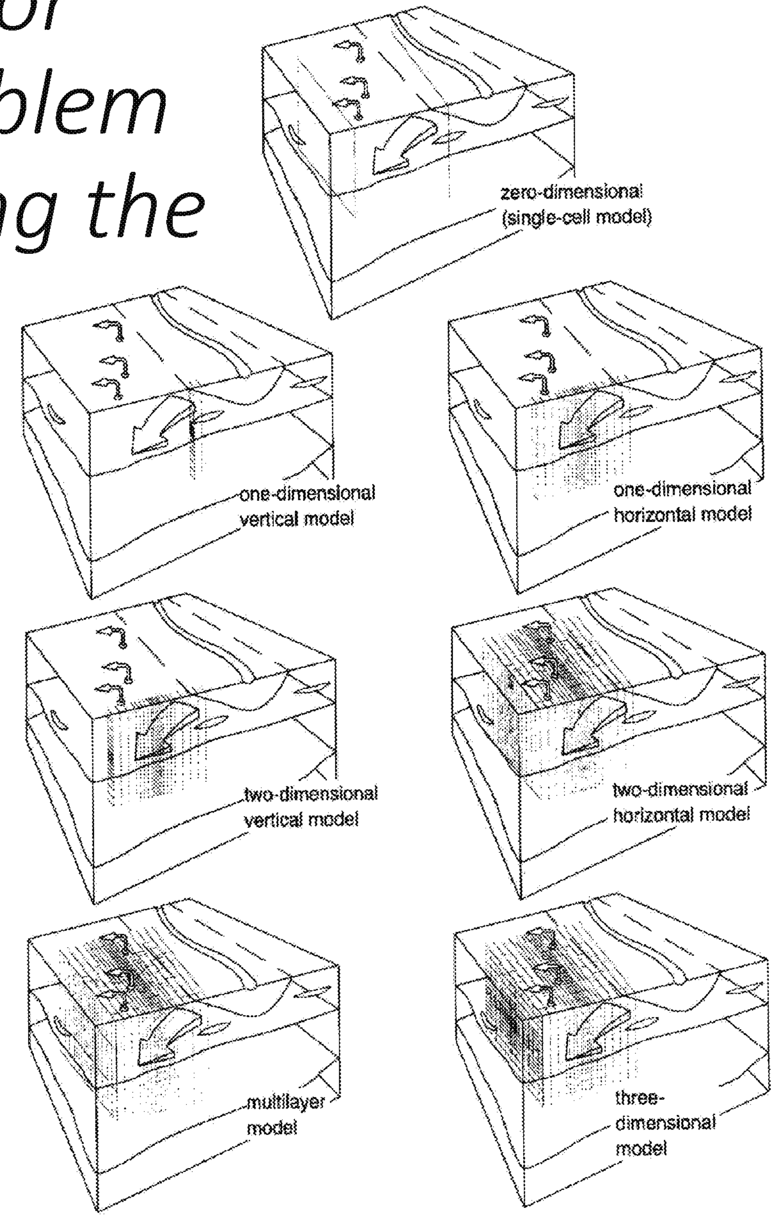


Figure 7.1 Common dimensional simplifications.

Modified after Spitz and Moreno (1996, Ch.7 "Dimensionality of Flow and Transport Problems")

Site Specific LNAPL Transport Evaluation-General Discussion

- Four classes of LNAPL vadose zone modeling approaches for this site:
  1. Dimensionless holding model (Navy's current approach)
  2. 2D longitudinal-transverse dynamic model
  3. 2D longitudinal-vertical dynamic model
  4. Fully 3D dynamic model
- Many limitations and uncertainties exist for each approach due to this complex environment
- Validation of these approaches is difficult, but our impression is the holding model cannot be field validated and classes 2-4 are very difficult to validate in the field
- Selecting an approach depends ultimately on the objective

Reviewing LNAPL Evaluation Approaches for Red Hill

Objectives

1. Dimensionless holding model (Navy's current approach):
    1. Initial calculations of attenuative capacity
    2. Focus: exploring fundamental concepts and sensitivities in the environment
2. 2D longitudinal-transverse dynamic model
    1. Physically-based evaluation of LNAPL lateral migration/spread potential
    2. Focus: Evaluating risk posed to Red Hill and Halawa Shafts (when linked with GW F&T model)
    3. Simplifying assumptions should be demonstrably protective in terms of RHS/HS
3. 2D longitudinal-vertical dynamic model
    1. Physically-based evaluation of LNAPL vertical migration/spread potential
    2. Focus: Evaluating risk posed to aquifer under tanks (no link with GW F&T model needed)
    3. Simplifying assumptions demonstrably protective of sole-source aquifer, not necessarily RHS/HS
4. Fully 3D dynamic model
    1. Provides all of the above
    2. Complex: only implement if (1), (2) or (3) unacceptable or unmitigable via response action

LNAPL Evaluation Approaches- Overview

Four Classes of LNAPL Vadose Zone Modeling Approaches			
1. Dimensionless Holding	2. 2D longitudinal-transverse dynamic	3. 2D longitudinal-vertical dynamic	4. Fully 3D dynamic
Previously undertaken, and currently being refined by Navy	Physically-based evaluation of LNAPL lateral migration/spread potential	Physically-based evaluation of LNAPL vertical migration/spread potential	May be able to cover all aspects of the other modeling approaches
Estimates overall bulk residualization capacity	Focuses on risk posed to Red Hill and Halawa Shafts when linked with GW F&T model	Focuses on risk posed to aquifer under tanks (link to GW F&T not critical but may be informative)	Resource intensive, difficult to produce
Explores some concepts and sensitivities, but only in residual and geologic dimensions	Uses simplified assumptions to protect drinking water sources	Uses simplified assumptions to protect sole-source aquifer, not necessarily drinking water supply	Difficult to validate in field
Underestimates potential for impacts and can not bound dynamic transport conditions	Difficult to validate in field	Difficult to validate in field	
Unable to validate in field			

Increasing complexity and computing demand

Increasing dimensions and realism

Not inherently conservative

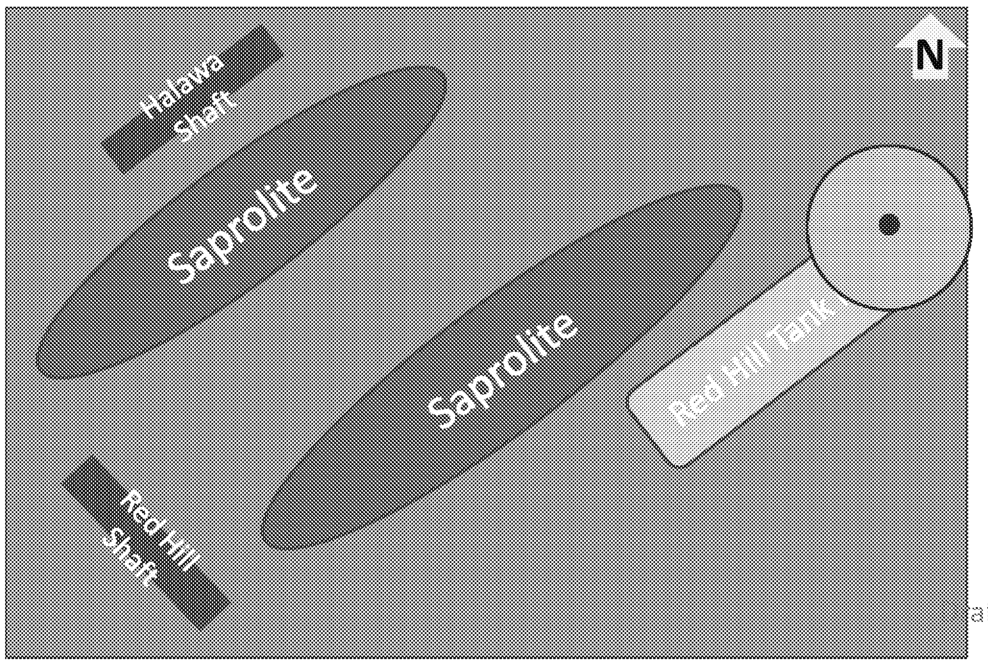
Generally decreasing conservatism

2D longitudinal-transverse dynamic model

- Focuses specifically on two receptors: 1) Halawa Shaft and 2) Red Hill Shaft
- Some aspects of the calculations are the same for both, some aspects differ
- Modeling approach is vertically-simplified but temporally-dynamic

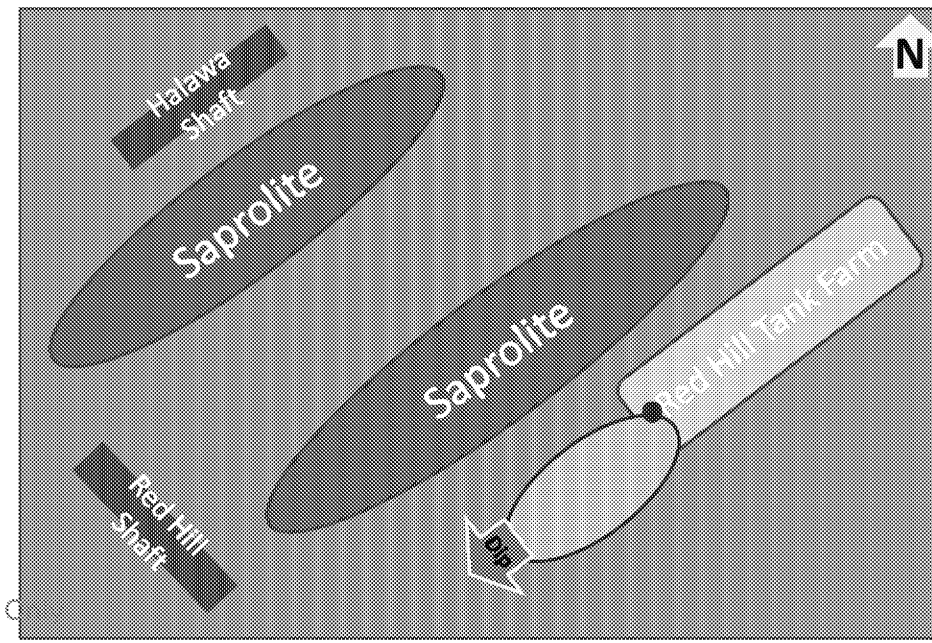
<u>Halawa Shaft Analysis</u>

- LNAPL release location assumed on NE end of tank farm
- Structural dip assumed negligible (i.e., flat units)



<u>Red Hill Shaft Analysis</u>

- LNAPL release location assumed on SW end of tank farm
- Structural dip assumed to SW at prevailing D&S values



2D longitudinal-transverse dynamic model
Common and Specific Aspects

- The following aspects will be the same for each receptor assessment:
  - LNAPL transport assumed to be dominantly longitudinal-transverse and to occur in the most transmissive materials only (i.e., two-dimensional [2D])
  - Vertical migration or inhibition ignored: assume that any vertical migration only reduces potential lateral migration (i.e., 2D analysis exaggerates lateral spreading)
  - Reduced attenuation capacity due to "stacking" of multiple releases accommodated
- The following aspects will be different for the two receptors:
  - LNAPL release location:
    - For HS - assumed on NE end of tank farm
    - For RHS – assumed on SW end of tank farm
  - Structural dip:
    - For HS - assumed no dip (i.e., flat units)
    - For RHS – assumed to SW at prevailing D&S values
  - Preferential pathways:
    - For HS – none?
    - For RHS – lava tube(s)?

2D longitudinal-transverse dynamic model

Release Scenarios

- Accommodates alternate release scenarios, volumes, rates, such as:
  - Large volume, slow rate (similar to 2014 release)
  - Large volume, fast rate (catastrophic release)
  - Small volume, slow rate (small chronic release)
- Mechanism, size, rate of release should be guided by tank integrity work, and 2014 release
- Conservatively, the modeling approach essentially assumes that release occurs directly into the / a transmissive unit (i.e., not against a tight flow interior):
  - However, conceptually, the slow rate releases could also be interpreted as potentially high-rate releases, that occurred adjacent to a tight flow interior and therefore were rate-limited

2D longitudinal-transverse dynamic model
Advantages

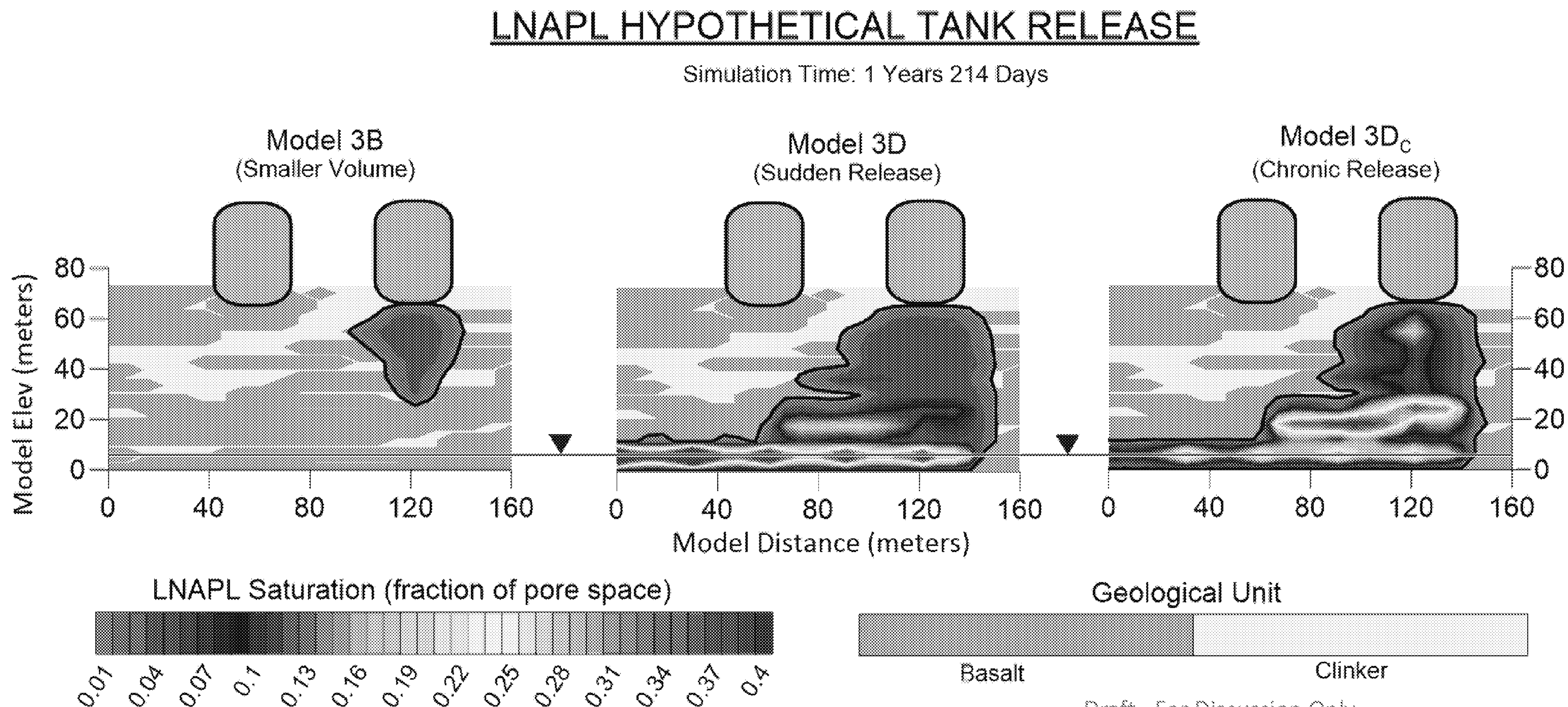
- Provides a conservatively-large footprint over which an LNAPL release may impact the water table:
  - Appropriate to goal of evaluating the potential risk posed to the two water providing potential receptors specifically
- Provides a time-varying (dynamic) mass loading function over a realistically-conservative footprint for use in the groundwater fate-and-transport model
- Calculations very tractable as they are 2D though potentially anisotropic / heterogeneous:
  - This facilitates multiple scenarios, sensitivity, and uncertainty analyses

2D longitudinal-transverse dynamic model
Limitations

- Does not directly address (relative) likelihood and timing of LNAPL moving vertically from release point to the water table:
  - Assumes there is negligible attenuation due to vertical transport processes
  - This can be evaluated using "*2D longitudinal-vertical dynamic model*" though is not required for making conservative vadose zone transport assumptions
- Likely underestimates the attenuative capacity of the vadose zone:
  - This is however consistent with the goal of evaluating risk to potential receptors at the water supplies
- Timing not easily validated using field data:
  - Validation limitations apply to all LNAPL modeling approaches
  - Spatial extent can be approximately validated using groundwater data after loading into the groundwater fate-and-transport model

2D longitudinal-vertical dynamic model
Overview

- Potential applicability to the Site previously demonstrated



Draft - For Discussion Only

2D longitudinal-vertical dynamic model

Overview

- Utility for evaluating relative timing and magnitude of impacts to aquifer of different release scenarios has been illustrated
- Advantages and limitations similar to those of "2D longitudinal-transverse dynamic model" but with specific regard to protectiveness of the underlying aquifer rather than protectiveness of the water supply shafts
- Does not directly address the relative likelihood and timing of LNAPL moving laterally from release point to the water supply shafts:
  - This can be evaluated using "*2D longitudinal-transverse dynamic model*"
- Spatial impacts not easily validated using field data:
  - Validation limitations apply to all LNAPL modeling approaches
  - Temporal impact can be approximately validated using groundwater data directly

Fully 3D dynamic model
Overview

- Not previously applied at the Site
- Would in essence incorporate all the features and capabilities of (1), (2) and (3) into a single model
- May not be possible to complete under current schedule
- Computational requirements likely to be prohibitive for undertaking multiple scenarios, sensitivity, and uncertainty analyses
- Validation limitations will apply to this, and all, LNAPL modeling approaches
- In theory, could be used to evaluate the likely fate of historical releases if sufficient field data were available to corroborate simulations, however this is unlikely to occur

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Relevant Bibliography

- Dixon, K.L., Lee, P.L., and Flach, G.P., 2008. A Graded Approach to Flow and Transport Modeling to Support Decommissioning Activities at the Savannah River Site. *Health Physics,* 94 (5 Suppl 2): S56-61. doi: 10.1097/01.HP.0000300756.69761.1e. May 2008.
- Neuman and Wierenga, 2003.
- Spitz and Moreno, 1996.
- United States Environmental Protection Agency (USEPA), 2009. *Guidance on the Development, Evaluation, and Application of Environmental Models*. EPA/100/K-09/003. March 2009.

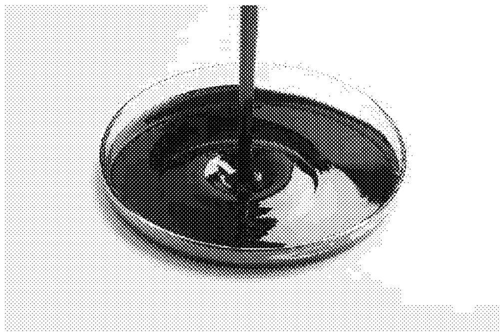
Conceptualization and Parameterization

Overview and Recommendations

Presented by G. D. Beckett, Aquiver

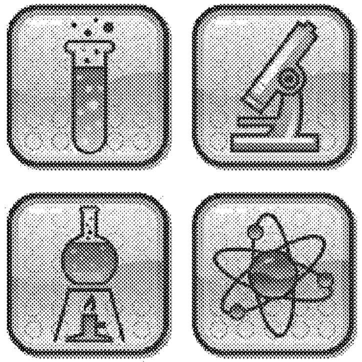
February, 2019

Topics



- LNAPL transport parameters
  - Most of which we have or can assume for now
- System architecture
  - We have extensive geologic mapping
  - Need to conceptualize the transport regime
- Release volume scenarios
  - As noted in prior slides
  - The releases drive the transport
- ***We cannot know/describe everything***
  - ***But we can evaluate important aspects***
  - ***Conservatively infer or measure***

Recall Some General Observations by Others



- Pore scale processes are important
  - But won't be seen at macro-scale
  - Homogenization can yield insights, but limited
- Heterogeneity ***<u>cannot</u>*** be modeled deterministically
  - Micro-scale phenomena appear semi-random
  - Stochastic approaches should be considered
    - *Abbreviated from Russell et al., NSF (2008)*
- Small volumes of LNAPL in ~vertical fractures can produce significant LNAPL heads:
  - Significant depth of penetration into aquifer possible
  - Monitoring well observations are not straightforward
- The presence of potentially mobile LNAPL beneath historical groundwater surface lows should be considered
    - *Abbreviated from Hardisty et al., J. of Eng. Geo & Hydro 2003*

Multiphase Flow & Factors

(note the parallels to standard g.w. flow)

$$q = -Ki \quad \& \quad v_p = {}^{-Ki}\!/_{\theta_e}$$

Nice Darcy

$$q_p = -k_r k_i \, {}^{\rho g}\!/_{\mu} \cdot i$$

Multiphase Darcy

$$\frac{\partial \theta}{\partial t} + \lambda = \frac{\partial}{\partial x}[q_x] + \frac{\partial}{\partial y}[q_y] + \frac{\partial}{\partial z}[q_z]$$

Continuity Eqn

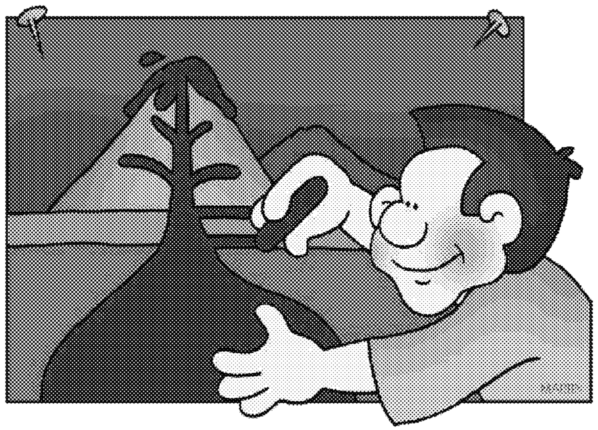
$$T_p = K_p b_p = \frac{\rho_p g}{\mu_p} \int k_{ij} k_r \partial z$$

Multiphase Transmissivity

$$Q = -\frac{4\rho g}{3\mu(\pi\alpha)^2} b^5 \partial h$$

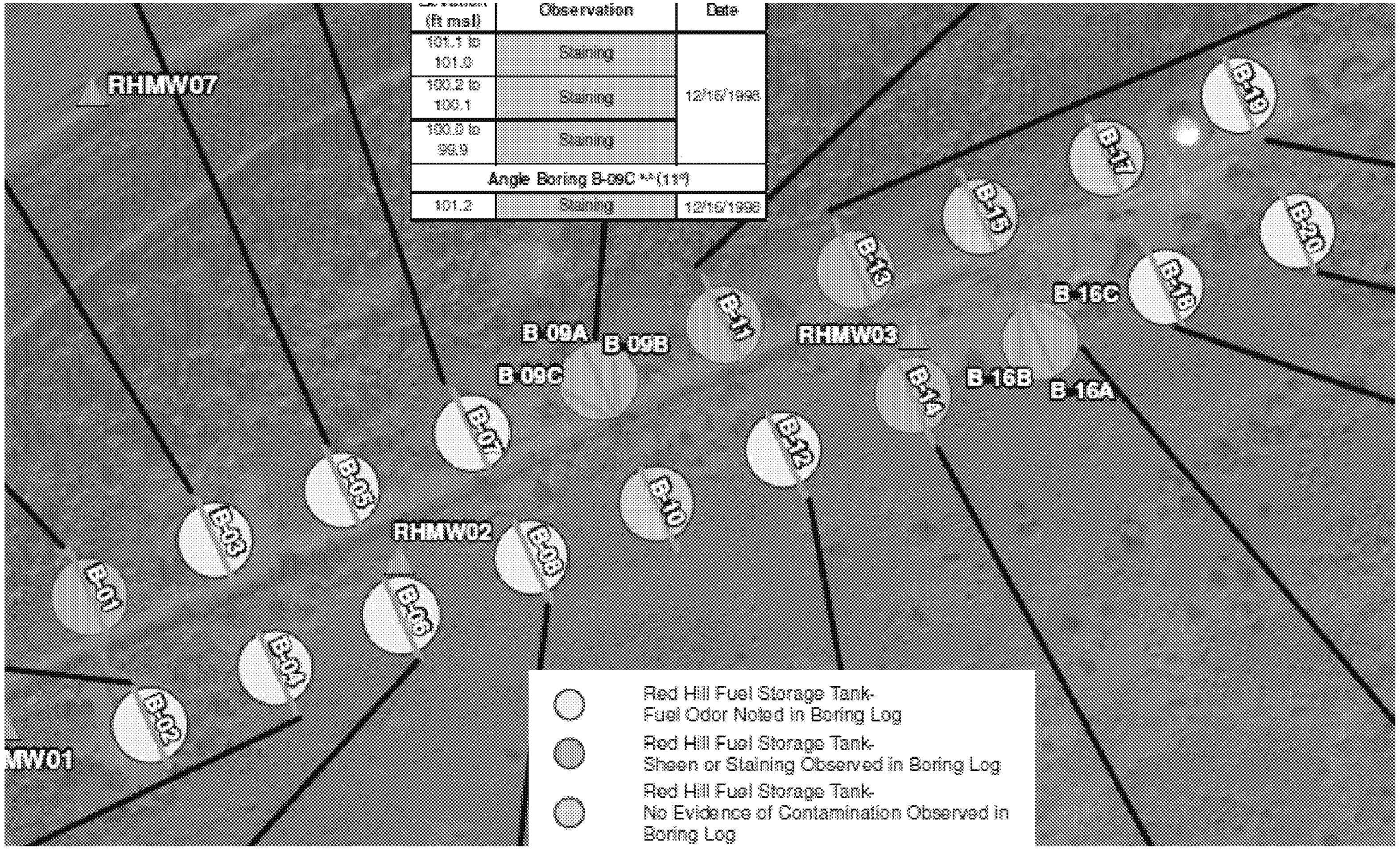
Void/Fracture Flow

Key Parameters Controlling LNAPL Transport



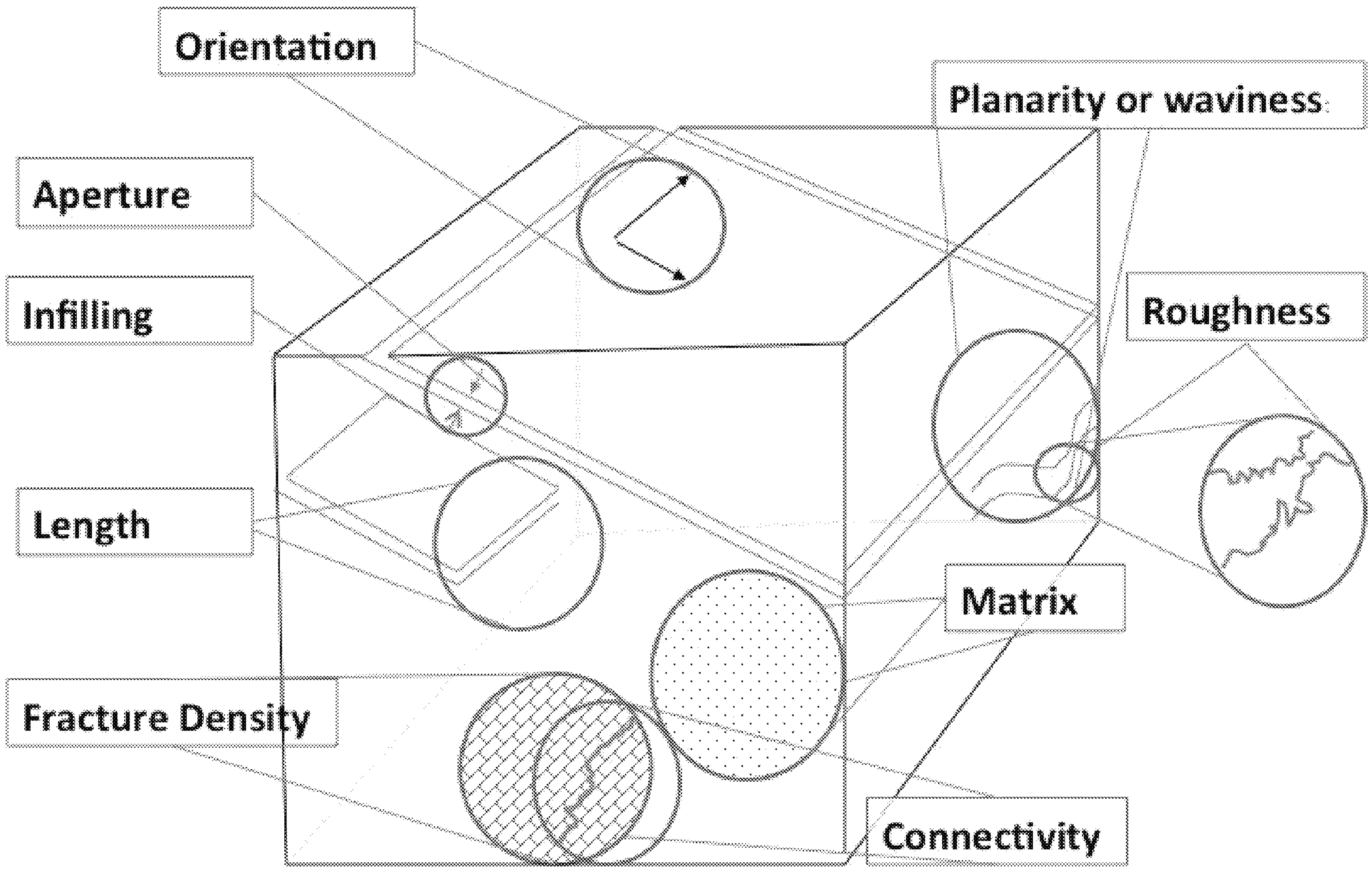
- Focus is on what we know or can conservatively assume
    - Recall limitations to petrophysical lab tests
- **Lithologic/soil parameters**
    - Capillarity – estimate from apertures & voids
    - Relative permeability – estimate from literature
        - Use a continuous function (e.g., van Genuchten/Mualem, 1976)
        - Step function less conservative and likely inapplicable
    - Permeability/Conductivity – already compiled
    - Wettability – Assume aquifer is water-wet
        - If vadose modeling done, simple lab tests to confirm
    - 2 & 3-phase residual saturation – measurement/estimation
        - This is a challenging factor, will require agreed range
        - Bounding end member, assume capacity is uptaken
            - Significant residual is/was present beneath many tanks
    - Porosity, compressibility & a few others – literature/site
- **Fluid properties**
    - Interfacial tension – simple lab test should be done
        - Site fuels and site groundwater - aged
    - Viscosity & Density – literature values are sufficient
- **Chemical composition** and links to daughter plumes
    - IE, dissolved- and/or vapor-phase sourced by fuels
    - Literature values already compiled are sufficient

Indications of Residual Impacts at Most Tanks



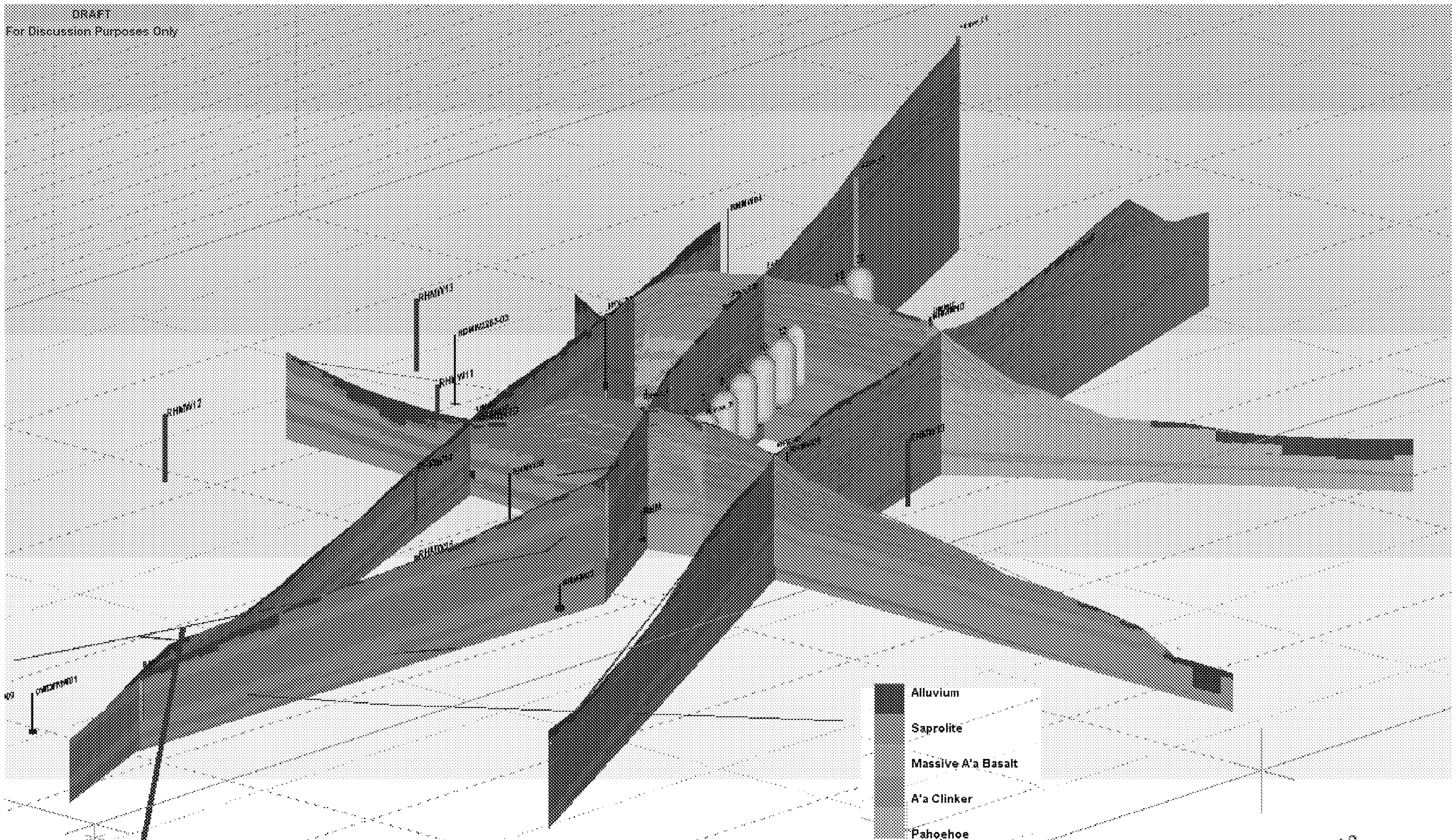
Navy CSM DRAFT Report, July 2018

ITRC Fractured Rock CSM - Architecture



A Solid Basis for Architecture Exists

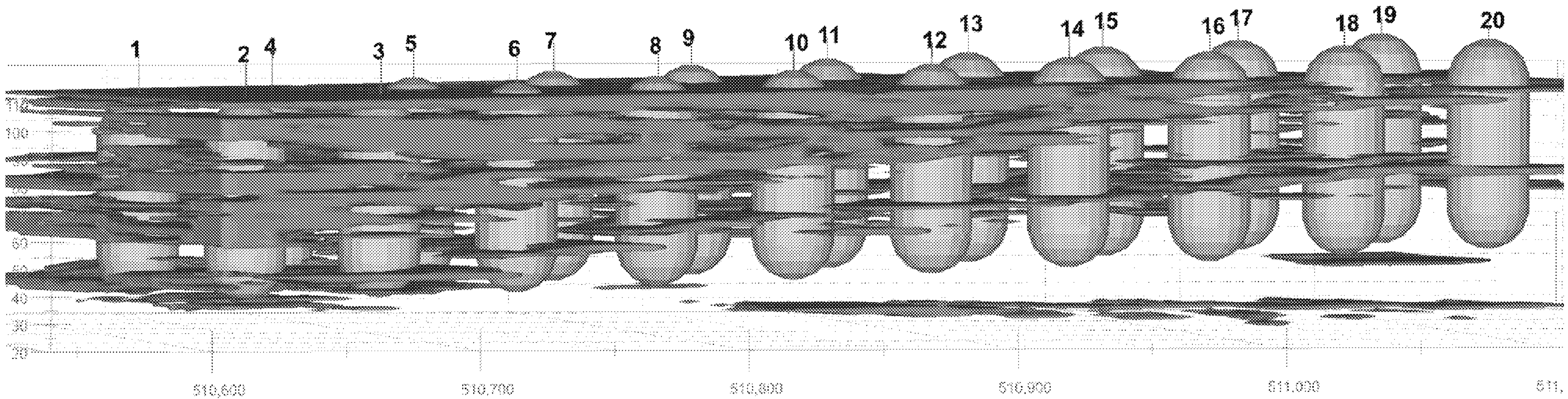
(we need to define the fine-scale connectivity)



(prior draft, since updated by Navy Team)

Interpreted Clinker Zones

(variability across tank field, similar variability at depth?)



(prior draft, since updated by Navy Team)

Thin Bedded Pāhoehoe Flows at Red Hill

(how do liquids travel through these zones?)

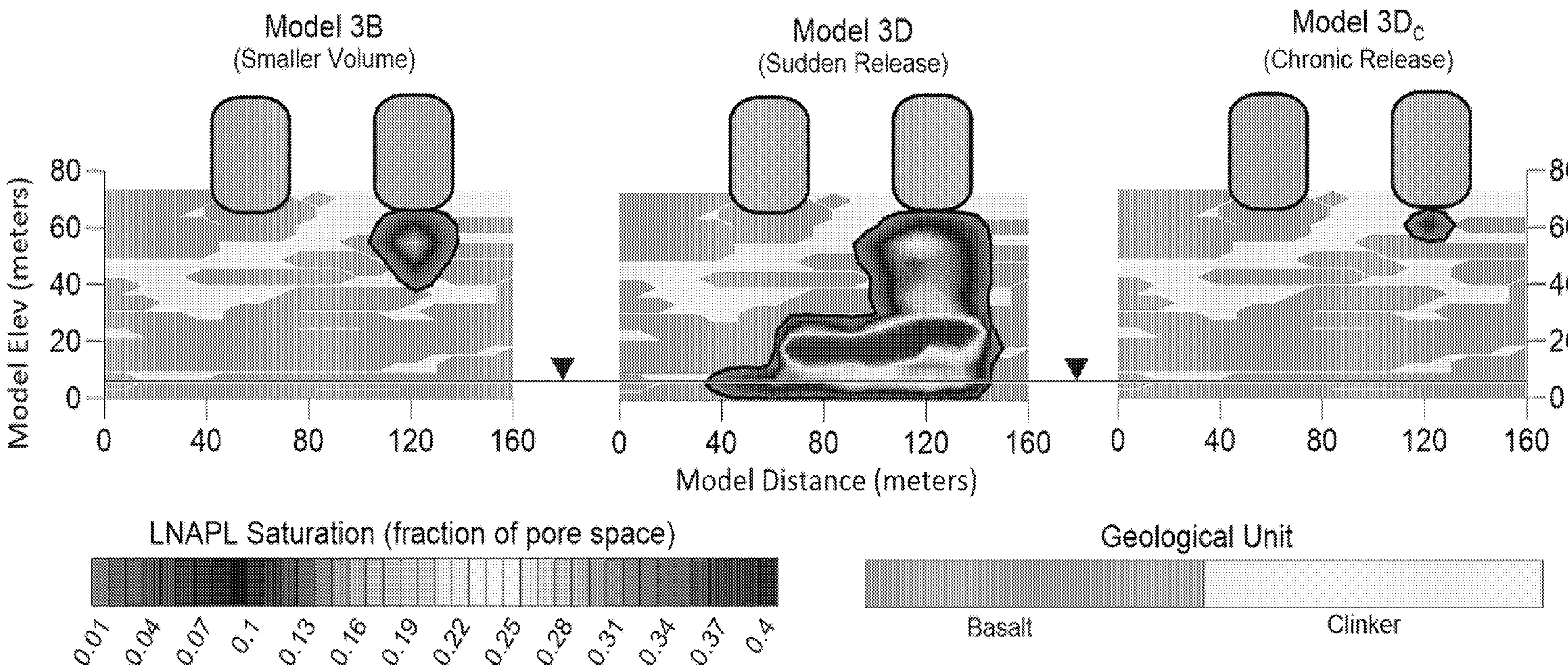
Connections to Clinker Zones

(another transport architecture to describe)

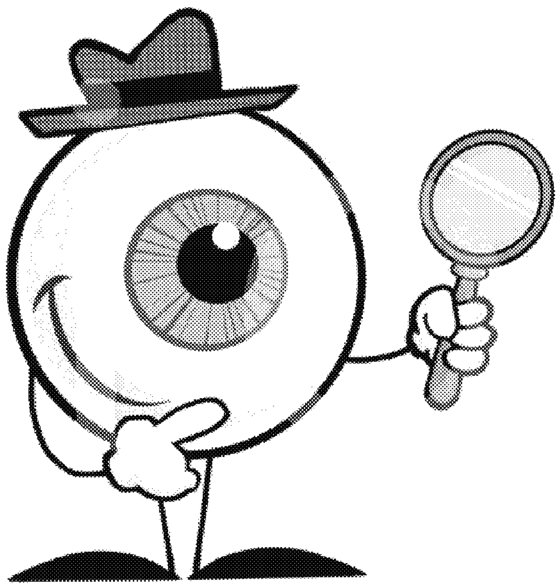
Big Island Exposure of Relatively Unweathered Area

Release Inputs & Residual Capacity

(just a reminder that release style/volume drive outcomes)



Summary



- We have most of the parameters needed
  - Most can be determined from available site data
  - Others can be assumed from literature
    - Augmented if/when sensitivity suggests
  - Site unknown – residual/how much remains?
    - Need to define a range – measurement/literature
    - Bench scale testing could be useful
    - Core/centrifuge often overestimates residual
- We need a close look at geologic architecture
  - What system(s) of behavior is suited?
  - How are voids/fractures interconnected?
  - How do they vary across the tank farm?
  - Initially use an EPM approach
    - Assess any non-conservative issues
- Both parameters & architecture are critical
  - But architecture is likely most important
  - Navy team has been compiling these elements

Regulatory Recommendation and Rationale

- Determining where a release will travel is not possible- conservative assumptions will need to be used
- 2D Transverse Dynamic Model is best for determining worst case transport to drinking water receptors
- Information from this LNAPL modeling can be used in the groundwater flow model to better estimate worst case impacts to drinking water receptors and may highlight need for standby wellhead treatment
- Determine under what circumstances the Navy may need to update the Contaminant Fate and Transport Model: New releases, releases of a certain size, etc.

Initial Depictions of Dissolved Oxygen (DO) Data in Groundwater

Prepared by M. Tonkin, S.S. Papadopulos & Associates, Inc. (SSP&A)

February 12, 2019

Animation of Dissolved Oxygen (DO)

Overview

- Dissolved oxygen (DO) measured in monitoring wells was interpolated to provide piece-wise continuous "grids" of DO concentration
- The grids were then animated to illustrate patterns of DO over time

Why Look at Dissolved Oxygen (DO)?

Degradation and (Co-)Metabolism

- Petroleum hydrocarbons biodegrade through the "oxidation" of bonds
- "Oxidation" refers to the transfer of electrons *not* oxygen. "Redox" reactions transfer elections from "donors" to "acceptors". That said …
- Oxygen is an efficient oxidizer and is usually preferentially utilized:
    - DO is plentiful in Hawaii due to high rainfall and the volcanic system (overall)
    - Measurement of DO in groundwater is common-place
    - DO is depleted in proportion to the mass of petroleum that is degraded
- The location and persistence of DO depletion relates primarily to:
    - The mass and the location of contaminants in groundwater
    - The longevity and character of petroleum-related impacts
    - The throughflow rate of groundwater carrying (i.e., replenishing) DO

In Summary

Regulatory Agency Interpretation of DO Data

- DO data may be used infer where contamination is, and has been, beneath and beyond Red Hill tank farm
- DO data may help interpret how long mass has been feeding the microbes in the aquifer
- DO data may be used to assess and inform the overarching Conceptual Site Model (CSMs) with respect to transport conditions and risk
- DO may be an important component of modeling to evaluate specific questions posed as alternate conceptual site models (ACSMs) such as:
  - *"Are distal detections of Total Petroleum Hydrocarbons (TPH) detections consistent with migration from Red Hill tank farm, or are they not?"*